Pre-Classroom Activities

Activity: Chain Reaction

Article: Destination Mars

For 25 years, robotic rovers have been traveling to Mars. Now researchers and scientists want to send *humans*. When humans travel to Mars, they won't be going by Space Shuttle. The Shuttle is designed specifically for low-Earth orbit, and Mars is more of a long-distance flight. Larry Kos, an aerospace engineer focusing on future flight technologies at NASA's Marshall Space Flight Center in Alabama, says there are three categories of likely travel to the red planet: chemical, solar-electric, and nuclear thermal propulsion.

Chemical propulsion uses materials and processes similar to the Delta 3 rockets in use now, Kos says. Part of the craft drops away once the initial launch propellants have been used; the fuel requirements for a spacecraft to Mars are much greater making the rocket heavier. Where the Delta rocket has one 25,000-pound thrust engine, Mars-bound rockets would need four." The technology and mechanics of chemical propulsion is already in existence.

Solar-electric propulsion (SEP) uses a combination of solar arrays and a liquid oxygen plus hydrogen kick stage to get the craft going. The use of solar power minimizes the amount of fuel and mass required for departure, Kos says. The down side of SEP is that has a low **thrust**. "SEP uses Newton's first law-that a small force, exerted continuously, will cause acceleration to grow very slowly," Kos says. "It's like the snowball-rolling-down-the-hill gathering momentum."

While chemical propulsion uses two powerful bursts of energy—one to attain mid-Earth orbit, and one to continue into interplanetary space—SEP makes many smaller orbits, each one spiraling out just a bit more. These continually spiraling orbits gradually increase in velocity, until they reach the proper speed to launch the second stage—the chemical stage—into space. It takes one year for the spiraling orbits to reach the proper speed. That adds tremendously to the time involved in a trip to Mars. One year is how long it takes to reach the secondary launch speed. From the secondary launch it is an additional 180 days to reach Mars. During that year of -increasing orbits, astronauts would not be aboard the spacecraft. They'd board it by means of a crew taxi vehicle, which would take the astronauts out to rendezvous with the spiraling craft just before it's ready to be propelled on its way to Mars.

Nuclear Propulsion is as lightweight as the SEP method, but it has the benefit of using the higher thrust propulsion of chemical rockets. It would take hours, rather than a year, to leave Earth's vicinity. The down side? Public perception, Kos says, is anti-nuclear. "Nuclear thermal propulsion is enriched uranium, not plutonium, so it is less radioactive by a factor of 100,000."

A trip to Mars is much more complex, both in scale and in distance, than any other space travel project contemplated to date. In order to have the supplies needed to set up facilities on the planet, multiple trips to Mars will be required. It just isn't practical to try and load everything onto one rocket. While options vary, depending on the type of propulsion used, researchers expect that a trip to Mars would entail six to eight individual launches.

In the first launch, the propellant production equipment would go ahead of the crew, land, and start robotically building propellant for the return trip. During the same trip, the habitat module would also go ahead of the Mars crew to be ready for the crew when it lands on Mars. Two or three launched vehicles would rendezvous in space, and their combined stages would be used to leave low-Earth orbit to deliver the payload for an eventual landing on Mars.

Even though science fiction movies depict the landing of a large rocket on the surface of Mars, the **transit** habitat would stay in orbit above the planet—much the way the command module did for Moon landings—while the crew lander takes a surface habitat to ferry astronauts down to the surface. The command module would also provide the transportation back to Earth; this, in combination with a small ascent capsule, saves the need for developing another rocket strong enough to blast off from the Mars surface.

The timetable for a human landing on Mars isn't definite, but scientists are hoping that the first Mars **stacks** might leave Earth around 2016, land around 2018, and return to Earth in 2020.

A flight to Mars depends on precise timing. The alignment of the planets allows for an optimal launch to take place every 26 months, Kos says. To launch at any other time would make it much more difficult for the rocket and the planet to be in the right place at the right time. Staggering launches like this would mean that multiple launches would need to be paced on a 26-month schedule, so a return trip back from Mars could only take place after the planets were again aligned properly.

Mars is about 1,000 times farther away than the Moon, Kos says, but the logistics of interplanetary speed means that it would only take about 50 times as long as a

Moon voyage to arrive at Mars: Apollo 11 took 4 days to reach its destination; Mars travel will take about 180 days.

Right now, we're not ready to go to Mars, Kos says. The risk of failure is too high, there are too many details to be resolved, and public support needs to be there. "We're headed in that direction, though, and that's what matters. Hopefully, at some point, we'll consider a Mars trip as routine as a Space Shuttle launch."

Courtesy of NASA's Space Operations Mission Directorate

Chain Reaction

Teacher Sheet(s)

Objective: To simulate a chain reaction.

Level: 9-12
Subjects(s): Chemistry
Prep Time: Less than 10 minutes
Duration: 40 minutes
Materials Category: Special Requirements

National Standards:
Science: 3a, 3e
Math:
Technology (ISTE):
Technology (ITEA):

Materials: *(per group of three to four)*

- 15-30 dominoes

Related Links:
NASA Space Transportation
Applet: Nuclear Chain Reaction

Supporting Article:
Destination Mars

Pre-Lesson Instruction:

- Divide students into groups of three to four.
- Each group of students will need 15 to 30 dominoes.
- Each group will need to work on a table or on the floor.

Background Information:
For a manned mission to a distant planet like Mars, a nuclear-propulsion system or nuclear-thermal system seems to be more advantageous in terms of propulsive power than a chemical system as a result of some basic differences. The two main features that lead to the advantages of a nuclear-thermal rocket

over a chemical one are the enormous energy available per unit mass of fission (or fusion) fuel, and that in a nuclear-thermal system the energy-producing medium is separate from the thrust-producing propellant.

Nuclear systems can use propellants of low molecular weight, which increase the propulsive force per unit propellant flow. The low molecular weight of the propellant permits for the use of a greater proportion of the total weight placed in space to be composed of the actual payload and not of the propellant. Low molecular weight propellants give mission designers a degree of flexibility for mission design that is not permitted by the chemical-propulsion system. With the use of a nuclear-propulsion system, mission designers can design missions that are more scientifically complex in nature because more equipment can be taken up into orbit.

Guidelines:

1. Read the article, "Destination Mars," and discuss the three methods of rocket propulsion.
2. Distribute dominoes.

Discussion/Wrap-up:

- Have students generate a list on the board of the advantages and disadvantages of a fission-propulsion system.
- Have each student write a paragraph summarizing a chain reaction.

Extensions:

- Demonstrate a model of a nuclear chain reaction. Assemble 30 to 50 mousetraps on a table, preferably next to a wall. Gently place a ping-pong ball on each set mousetrap. Drop a single ball onto the center of the assembly to start the demonstration. Within seconds there are balls flying everywhere, and, just as suddenly, the demonstration is complete. Each mousetrap represents the nucleus of a uranium or plutonium atom, and each ball represents a neutron. When fission occurs, a nucleus splits into several pieces, and also emits a number of neutrons. Each of these neutrons can strike other nuclei, causing fission. When a mousetrap is triggered, it propels the two balls into the air, which may then set off other traps. By setting the mousetraps next to a wall, this will maximize the possibility of any neutrons rebounding and initiating more neutron releases.
- Discuss the differences between nuclear fission and fusion.

Chain Reaction

Student Sheet(s)

Background Information:
Nuclear propulsion is a very attractive option for human exploration and development of space. Nuclear fuel could enable rapid, affordable access to any point in the solar system. The first step toward using advanced fission-propulsion systems is development of a safe, affordable fission system. Fission is one of the advanced concepts studied at NASA's Marshall Space Flight Center in Huntsville, Alabama.

A tremendous amount of energy is required to send a spacecraft to other planets and destinations within and beyond our solar system. Current systems have essentially pushed chemical rockets to their performance limits. The energy density of fission is 10 million times that of chemical reactions, such as the liquid oxygen/hydrogen combustion used to power the Space Shuttle. Applying fission to a soda can full of uranium—about 2 pounds—could produce as much energy as 100 Shuttle external tanks or 52 million gallons of liquid oxygen and hydrogen propellants.

Fission propulsion was worked on intensely during the Apollo years. In its current form, fission propulsion could be used to transport humans to Mars or to send sophisticated robotic probes into the outer reaches of the solar system. A trip to Mars could take less than 3 months and a journey to Jupiter could be completed in less than 1 year.

A well-designed fission-propulsion system would be inexpensive to build. Systems could be designed to operate for only a few hours or up to 20 years, depending on mission requirements. The fission process would initiate in space with the splitting of uranium fuel into two or more elements, resulting in liberation of tremendous amounts of energy. The fuel is nonradioactive throughout prelaunch activities and the launch itself, and does not begin accumulating radioactive material until it has started up in space.

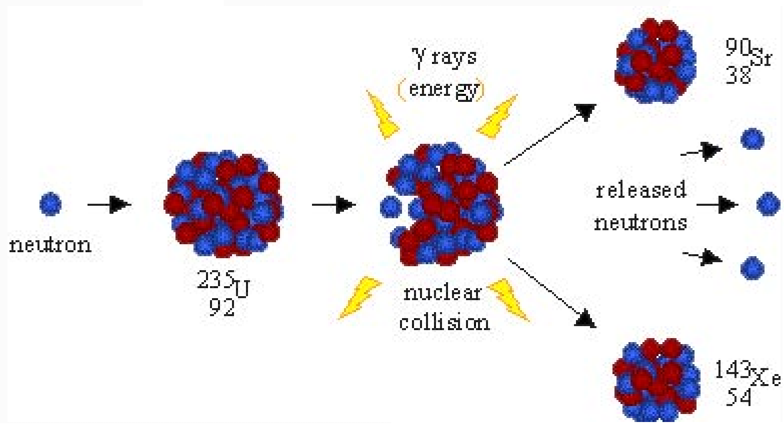
Despite their tremendous potential for enhancing or enabling deep-space and planetary missions, space fission systems have only been used in Earth orbit. The U.S. and the former Soviet Union have flown fission systems that provide power to satellites.

Besides reducing the cost of this type of space mission, nuclear-propulsion systems also have advantages for the crew in terms of time and health. For the

crew, the use of a nuclear-propulsion system means a minimized exposure time to microgravity, solar flares, and ambient space radiation, and a greater portion of the mission spent on the target planet.
Microgravity over prolonged periods of time can be detrimental to the health of crewmembers. This reduction in gravity causes the loss of calcium from the bones and the loss of muscle tissue, which may result in a crew that is incapable of carrying out the tasks necessary for its survival. The minimum exposure to this phenomenon, which results from the use of a nuclear-propulsion system, provides mission designers with a high degree of confidence that the crew will be able to carry out mission tasks both during the transfer orbit and during the exploration of the destination planet.

Nuclear Fission is a reaction in which an atom's nucleus splits into smaller parts, releasing a large amount of energy in the process. Most commonly, this is done by 'firing' a neutron at the nucleus of an atom. The energy of the neutron 'bullet' causes the target element to split into two (or more) elements that are lighter than the parent atom.

The Fission Reaction of Uranium-235

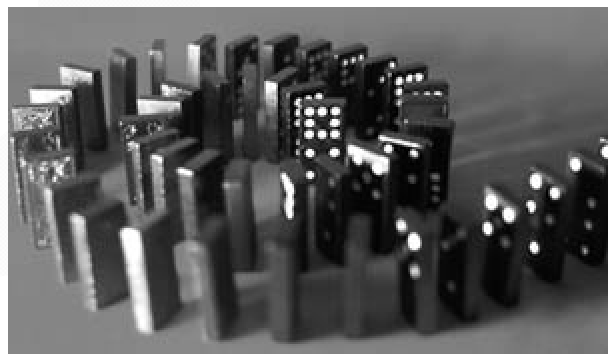


During the fission of U235, three neutrons are released in addition to the two daughter atoms. If these released neutrons collide with nearby U235 nuclei, they can stimulate the fission of these atoms and start a self-sustaining nuclear chain reaction. This chain reaction is the basis of nuclear power. As uranium atoms continue to split, a significant amount of energy is released from the reaction. The heat released during this reaction is harvested and used to generate electrical energy.

A chain reaction, once started, continues without further outside influence. Proper conditions for a chain reaction depend not only on various external factors, such as temperature, but also on the quantity and shape of the substance undergoing the reaction. A chain reaction can be of various types, but nuclear chain reactions are the best known. A line of dominoes falling after the first one has been pushed is an example of a mechanical chain reaction; a pile of

wood burning after it has been kindled is an example of a chemical chain reaction. In the latter case each piece of wood, as it burns, must release enough heat to bring nearby pieces to the kindling point. The wood, therefore, must be piled close enough together so that little heat is lost to the surrounding air.
In the case of the fission of a nucleus, the reaction is begun by the absorption of a slow neutron. When one atom fissions, a certain amount of energy is released, along with (let us say) two neutrons. If those extra neutrons cause two more atoms to fission, then twice as much energy is released along with four more neutrons. The new neutrons may cause another four atoms to fission, adding four times as much energy and eight more neutrons; so the total energy grows, doubling with each new generation of neutrons. The result is a stupendous release of energy.

Procedure:



1. Obtain a set of dominoes (around 30). Arrange and set up the dominoes so that when one falls, it will knock over the succession. Make a sketch of your design.
2. Knock over the lead domino. Observe the effect on the other dominoes. Observe the effect on the other dominoes.
3. Would you call this an expanding (out of control) or limited (controlled) chain reaction? Why?
4. Set up the dominoes again. This time set up only a few dominoes the same way as in the first arrangement. Arrange the others so that when they fall, they will knock over only one other domino or none at all. Make a sketch of your design.
5. Knock over the lead domino. Observe the reaction. Is it an expanding or a limited chain reaction? Why?
6. What could you do to stop the reaction once it begins?
7. Do you think this method would be equally useful in stopping the reaction when the number of dominoes is increased? Why?
8. How is the domino simulation like a nuclear chain reaction?
9. How is it different?

Questions:

1. Define the term nuclear fission and nuclear fusion. Which process results in the production of a heavier nucleus? Which results in the production of smaller nuclei?
2. How do the energies released by nuclear processes compare in magnitude with the energies of ordinary chemical processes?
3. What is the source of the energy released during nuclear fission?
4. Describe the concept of a chain reaction.

5. Explain why a chain reaction keeps going.
6. The explosive power of an uncontrolled nuclear chain reaction can be illustrated by means of a simple mathematical analogy. Imagine a job that pays 2 cents the first day, 4 cents the second day, 8 cents the third day, and so on, doubling each day. How much money will such a job earn over a 60-day period?
7. Can you think of another way to model a nuclear chain reaction?
8. Explain what advantages and disadvantages there might be to using nuclear fission in spacecrafts.